VISIT…

CIRCULATING OIL SYSTEMS

A. J. Twidale and D. C. J. Williams

INTRODUCTION

Use of a circulating system is commonly dictated by requirements of machine elements for a constant and copious supply of clean oil delivered at the correct temperature and pressure. An essential feature of the design is to ensure that the oil does not become too hot and is cleaned of its contaminants as a regular procedure.

All circulating systems need certain basic equipment: a reservoir, a pump, and pipework. Filtration and control of temperature, pressure and flow are also necessary; and isolating valves have to be provided to facilitate the maintenance of these controls and the machine being lubricated. These in turn call for suitable safeguards such as relief valves, pressure gauges, pressure and flow signaling devices, a standby pump, etc. When ingress of water or dirt is expected, a second reservoir may be necessary. Although variations are numerous, Figure 1 shows a typical arrangement. Basic capacities and components are listed in Table 1.

RESERVOIRS

The reservoir provides storage for the oil, allows sufficient dwell time for separation of air entrained as foam, for water and solid impurities to settle by gravity, and provides a reserve against losses. The reservoir should be located beneath the equipment on a 75-mm high subbase so that the oil can return by gravity through drain lines. Where this is not possible, a smaller collecting tank and sump pump must be provided.

Capacity

The minimum total reservoir capacity is determined by the following:

Working capacity — This consists of the total machine requirement at maximum anticipated flow multiplied by dwell time in minutes — see Table 1.

Drain back capacity — The total amount of oil in circulation will normally return to the reservoir when the pumps are stopped in no longer than 3 min. This volume may be calculated by multiplying the flow rate by a factor of 1 to 3. Add to this the capacity of any header, pressure, or collector tanks.

Air space — Allowance for thermal expansion, foam, and venting normally comprises approximately 1 min of flow rate or a minimum of 100-mm height.

Allowance for drain back capacity and air space must exceed the volume of oil retained in the system filter, cooler, delivery pipework and machine sumps that does not drain back when the pumps are stopped. This is to ensure adequate reservoir size to receive the oil required to fill the system initially and during maintenance.

Proportions

Head room and available space are important factors when deciding reservoir proportions. The largest oil surface area possible is desirable where entrained air is anticipated. The most suitable porportions frequently are width = height = length/2.

Connections

A sloping bottom of 1 in 30 with the pump suction at the high end and drain connections at the lowest point allows water and other impurities to be drained off. A floating suction

Copyright © 1983 CRC Press LLC

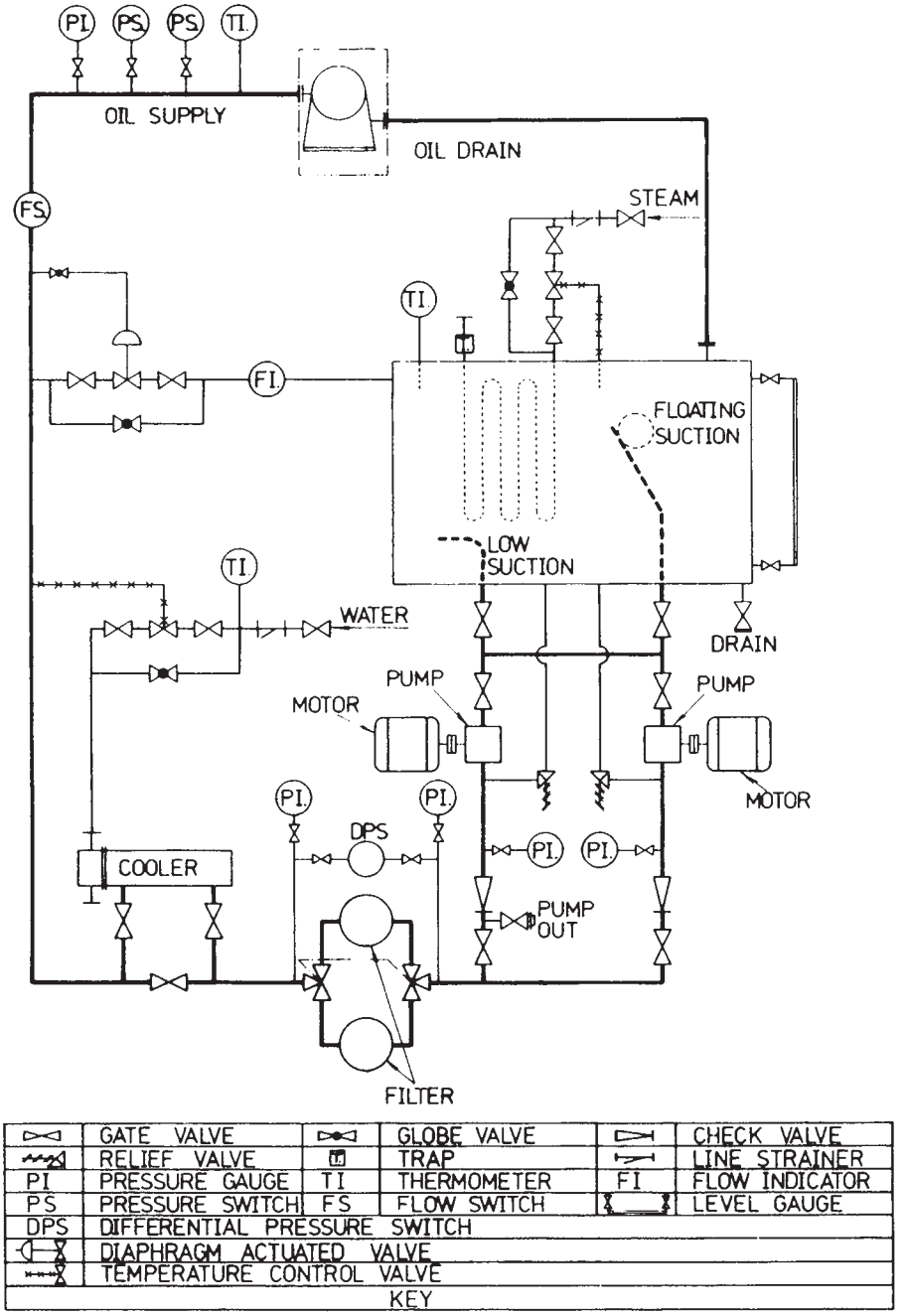


FIGURE 1. Typical system arrangement.

is necessary where heavy contamination is possible, as in large rolling mill systems where mill scale, water, and other impurities may occur. This is arranged to take oil appreciably above the water level but sufficiently below the surface to avoid entraining surface debris or foam. To minimize splashing and foam generation, the returning oil should discharge at or just below the operating level. In some cases, drain piping may desirably be positioned so that return oil can be inspected and a return filter provided (see Figure 2).

Suction and drain connections may be separated by baffles. By promoting a tortuous path

Copyright © 1983 CRC Press LLC

Table 1
CHARACTERISTICS OF TYPICAL OIL CIRCULATING SYSTEMS

		Machine requirement						Pump			Filtration		Cooler		Reservoir
		Oil viscosity at 40°C													
Application	Duty	SSU	cSt	gal/min	ℓ/min	lb/in.^{2}	Bar	Type	Main driver	Standby driver	Type	μm	Type	Temperature reduction (°C)	Dwell time (min)
Small electrical machinery	Bearings	350	75	1	4	15	1	Gear	Motor		Line strainer or mechanically cleaning	150	Shell and tube	45—40	5
Paper mill dryer section	Bearings and gears	700	150	20	75	45	3	Gear	Motor	Motor	Dual basket and centrifuge	120	Shell and tube	60—40	40 (Twin reservoirs to permit settling)
Steel mill	Bearings	1500	300	170	650	60	4	Gear	Motor	Motor	Dual basket and centrifuge	120	Shell and tube	50—40	40 (Twin reservoirs to permit settling)
Steel mill	Gears	1620	350	240	900	50	3.5	Gear	Motor	Motor	Mechanically cleaning (motorized)	150	Plate	50—40	20
General	Bearings	1000	200	10	40	15	1	Gear	Machine shaft or motor	Motor	Dual basket	100	Shell and tube	50—40	12
Grinding mills	Shaft jacking	2000	450	5	20	3000	200	Hydraulic	Motor	—	Disposable	20	—	—	12
Petroleum gas compressors	Compressor bearings and seals	150	32	50	200	150		Screw	Steam turbine	Motor	Disposable	10	Radiator or shell and tube	65—50	8
Petroleum steam turbines and generators	Bearings and controls	150	32	1700	6500	90	6	Centrifugal	Steam turbine	Motor plus DC motor-driven emergency pump	Disposable	10	Radiator	60—45	8

Copyright © 1983 CRC Press LLC

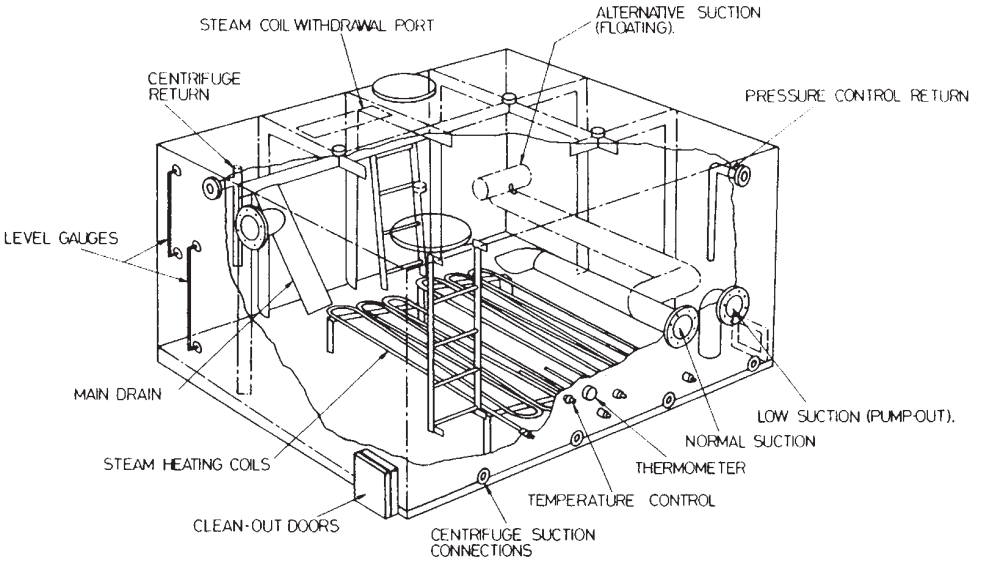


FIGURE 2. Typical reservoir layout.

between inlet and outlet, baffles enable the best use of the reservoir volume, eliminating dead pockets and assisting in deaeration and settling contaminants. A single-vertical baffle can form a weir to localize contamination and turbulence. Oil should flow across the weir as smoothly as possible to avoid cascading and frothing.

Due to fluctuation of oil levels and to permit the escape of moisture and vapor, the reservoir must be adequately vented. In dirty environments, these vents may incorporate filters to minimize intake of foreign matter. Access is necessary for inspection and cleaning.

Finish

After fabrication the internal surfaces must be thoroughly cleaned, either mechanically or by grit blasting, and a coat of oil-resistant paint applied to all surfaces excluding welds. After a 24-hr hydrostatic test, the painting should be completed.

Reservoir Heating

Heaters should raise the oil from ambient to the specified operating temperature, normally 40°C, within 4 hr. A further controlled increase in temperature will aid release of contaminants. Permanent heating arrangements are usually electric or steam.

Steam heaters are normally in the form of a continuous coil of 3/4 in. (20 mm) nominal bore seamless steel pipe. For every 4000 ℓ reservoir capacity, the coils should be 12-m long and will consume 30 kg/hr of steam at 3.5 bar. Pipe joints must be welded and pressure tested; no mechanical connections should he permitted within the reservoir.

Electric heaters fitted through the side of the reservoir should be provided with sheaths containing replaceable elements. This facilitates removal of a faulty element without having to empty the tank. The heaters should be controlled by thermostats and a low-level switch should interrupt the electrical supply should the oil level drop exposing the heaters. They should be 1 kW for every 400 ℓ reservoir capacity.

Whichever type of heater is used, temperature of the heat transfer surface must be low enough to avoid decomposition of the oil. For steam, the pressure should not exceed 3.5 bar which is equivalent to 150°C. For electric heaters, surface temperature is controlled by limiting the watts rating per surface area which varies depending on viscosity.

Copyright © 1983 CRC Press LLC

Viscosity		Watts rating	
SSU	**cSt**	**in.^{2}**	**cm^2**
300	65	8	1.25
300—1160	65—250	6	1.0
1160 and above	250 and above	4	0.75

PUMPS

The following system requirements governing pump size may also influence the choice of pump type.

Rate of flow — Some excess capacity must be provided as a safety margin to offset changes in system demand, a worn pump, wear in bearings, seals, etc. Basic pump sizing is between 110 and 125% of the equipment requirement for large systems; actual selection may exceed this because of standard pump sizes available.

Viscosity — Operating temperature range and the resultant viscosity variance affects the pump size and its driving power requirements.

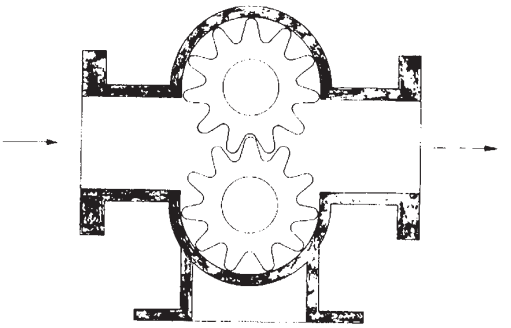
Suction conditions — The type of pump and/or actual positioning of the pump is governed by suction conditions. If installed above the oil level, the pump must be self priming and capable of producing the necessary suction lift.

Supply pressure — Design pressure at the pump is the sum of (1) required pressure at point of application, (2) static delivery head, (3) friction losses in piping and equipment, (4) filter drop when cleaning is necessary, and (5) an allowance for pump protection as follows.

Protection — Relief valves for protection of positive displacement pumps and drivers should be sized to pass full pump flow at a pressure not more than 25% above the valve "set-pressure". To determine "set-pressure" add 0.7 bar (10 psi) to the maximum pumping pressure in 0 to 7 bar range or add 10% for pump operating above 7 bar. Select the valve to be used, then ascertain the actual pressure when passing full flow at maximum viscosity. When the valve is integral with the pump, the manufacturer will have taken this into account.

Choice of Pump Type

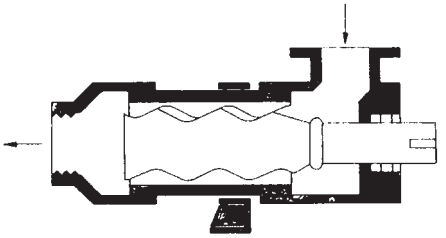
Positive displacement rotary pumps are generally employed for lubrication purposes because their rate-of-delivery is substantially unaffected by changes in delivery pressure and viscosity. Centrifugal pumps can also be used; since rate of delivery is then a function of pressure, related factors such as flow-demand, temperature and viscosity must be accurately controlled. The pump supplier can confirm the choice of pump and determine maximum absorbed power so that the driver can be selected. Pump types frequently used are as follows.



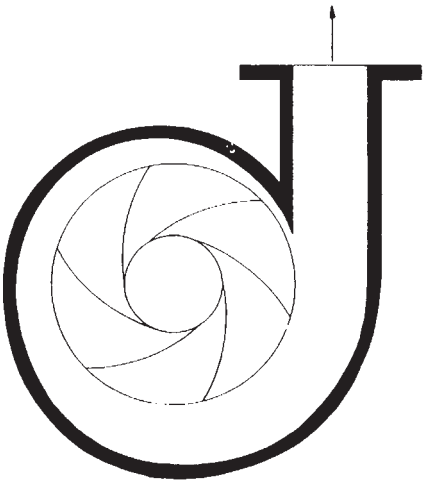
Gear pump — Positive displacement, relatively cheap, compact, simple in design. Where quieter operation is necessary, helical or double helical pattern may be used. Both types

Copyright © 1983 CRC Press LLC

capable of handling dirty oil. Available to deliver up to 150 ℓ/min and 70 bar (1000 psi). Self-priming with 7.5 m maximum suction lift.



Screw pump — Positive displacement, quiet running, pulseless flow, ideal for pumping low-viscosity oils, can operate continuously at high speeds over long periods, lower power consumption. Available to delivery up to 5000 ℓ/min and 70 bar. Self priming with 7.5 m maximum suction lift.



Centrifugal pump — High rate of delivery at moderate pressure; can operate with greatly restricted output, but protection against overheating necessary with no flow condition by permitting continuous bleed through restrictor in bypass line. Will handle dirty oil. Limited to oil viscosities below 250 cSt. Available to deliver up to 9000 ℓ/min and 12 bar. Flooded suction required to prime.

PURIFICATION AND FILTRATION

The degree of cleanliness chosen will depend on machine requirements. For most industrial applications, general practice uses filtration of 50 to 150 μm. The most common contaminants are water, dirt and dust, or carbon and sludge which can develop from oxidation of the oil. Purification schemes frequently used are as follows.

Settling

This is frequently the first resort in oil reconditioning and separates water and solid impurities from the oil when the system is at rest. Effectiveness of settling is indicated by the following settlement rates for particles in still, 30 cSt oil.

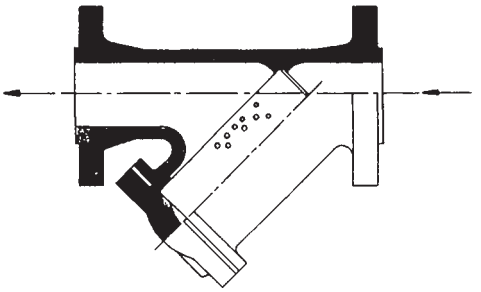
Copyright © 1983 CRC Press LLC

Particle diameter (μm)	Order of size	Time to settle
1	Fine dust	6 months
10	Silt	4 days
100	Fine sand	30 min
1,000	Coarse sand	15 sec

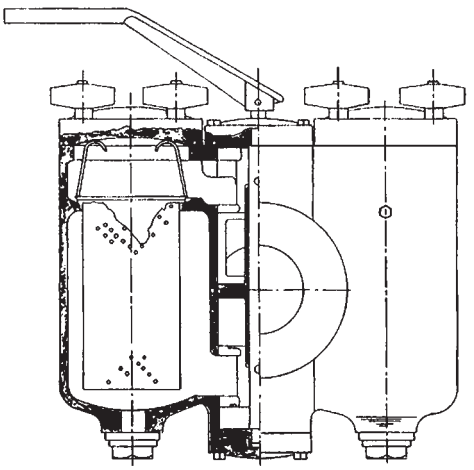
The table shows that only large particles will settle within practical time limits. Water settling is hastened by raising the bulk temperature to 70°C after which it can be drained from the bottom of the reservoir.

Filtration

This is the most universal method and many filter materials and designs are available. Filters should be selected so that under clean conditions and maximum working viscosity the pressure loss does not exceed 0.3 bar (5 psi). Cleaning is normally recommended when pressure loss increases by 1 bar. Filters usually fall within the following types.

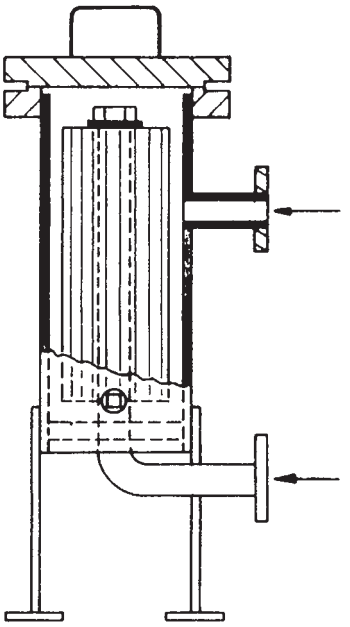


Line strainer — Woven gauze or perforated metal element; easily removed for hand cleaning when system stopped. Normally 150 μm and above.

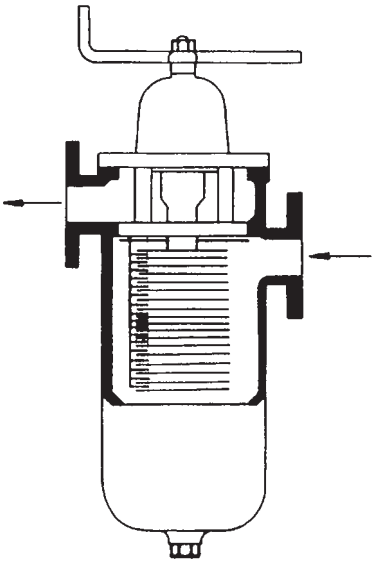


Dual basket filter — Woven gauze or perforated metal element with changeover valve; elements easily removed for hand cleaning when system in operation. Magnets can be incorporated. Normally 50 μm and above.

Copyright © 1983 CRC Press LLC



Disposable element filter — Element of materials such as treated paper, felt, and nylon easily replaced when system stopped. Dual versions with changeover valve permit element replacement when system operating. Normally below 50 μm.



Mechanically cleaning filter — Interleaved radial plates plough the dirt from the gaps between metal discs when the filter pack is rotated, which can be while the system is operating. May be motorized. Periodically drain contaminant from sump when system is stopped. Normally 150 μm and above.

Various other designs of mechanically cleaning filter, such as wire wound and back flushing, are available.

Copyright © 1983 CRC Press LLC

Centrifuging

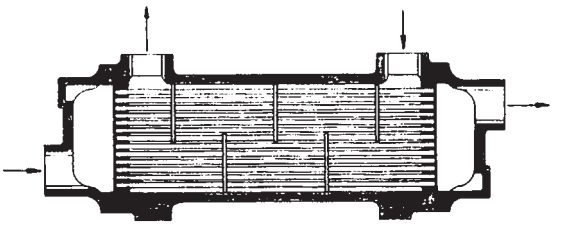
Installed in a by-pass circuit. Removal of sediment and water can be carried out while the oil system is in operation. For maximum efficiency, the oil should be centrifuged at 70°C with provision of an inline oil heater.

COOLERS

Constant oil temperature desirably enables constant flow and pressure control as these are both affected by changes in viscosity. Most machine designers recommend that the working temperature of the oil be 40°C. High-ambient temperatures, heat generation from bearings and gears, and machine and oil pump inlet power all transfer heat into the oil. The amount of heat is normally specified by the machine designer or based on experience with similar units. This commonly amounts to an oil temperature increase through the machine in the region of 10°C which needs to be removed by a cooler. Prolonged working temperatures above 60°C shorten oil life.

Water and air are the common cooling mediums. When considering water, its cleanliness, corrosion characteristics, hardness, and pressure will affect selection of cooler materials. Temperature, quality, and quantity of cooling medium available are important in obtaining the most efficient cooler. Pressure losses for oil or water through the cooler should not exceed 0.7 bar.

Cooler types frequently used are as follows:



Shell and tube — Oil through shell, water through tubes. Requires space for tube removal.

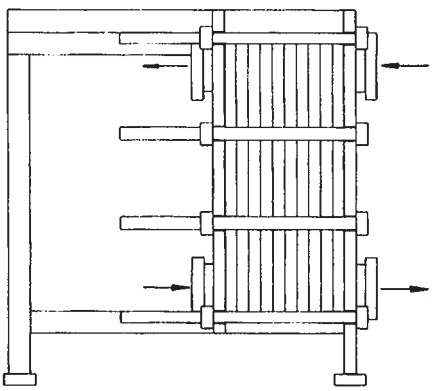
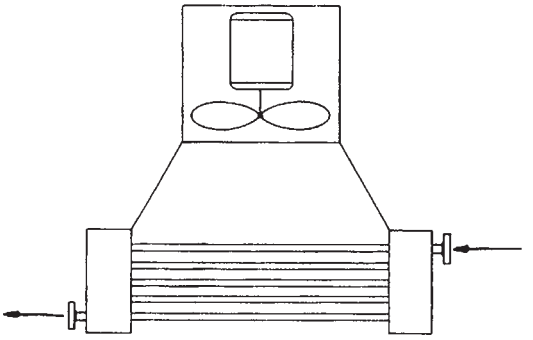


Plate — Oil and water between alternate plates. Compact and readily separated for cleaning.

Copyright © 1983 CRC Press LLC



Radiator — Oil through tubes, air over tubes motivated by fan.

TEMPERATURE CONTROL

Along with heaters and coolers, controls are required to cope with inevitable temperature fluctuations.

Reservoir Heater

The control thermostat or thermostatic valve probe, Figure 3, should be positioned near the pump suction and at about middepth of the oil in the reservoir to sense the average temperature. Ensure that the thermostat is never exposed or placed near any localized hot spot such as a heater.

Oil Cooler

One control method is to regulate the water/air flow, the other to regulate the flow of oil to be cooled. Water flow can be governed by a hand control valve as its temperature usually only fluctuates on a seasonal basis. Automatic control of air is essential as its temperature fluctuates daily.

Automatic control utilizes a direct-acting modulating valve in the cooling water supply line which is controlled by a sensing element in the cooling oil outlet. The effect on oil temperature is not instantaneous but is generally acceptable for industrial systems. Cooling water pressure should be reasonably stable, otherwise a pressure regulating valve will be required.

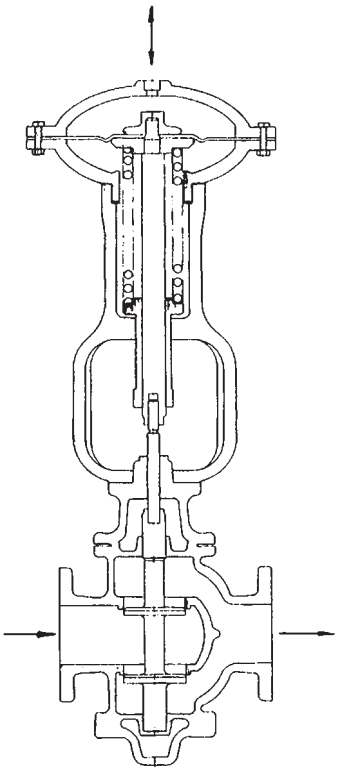
Alternatively, where instantaneous response to control is vital and/or where air is the cooling medium, the cooler should be provided with a bypass line and a control valve to divert flow into the bypass. The valve is of a three-way type with overlapping ports, Figure 4. Mixing of the oil streams within the valve produces an average temperature and a thermostatic element detects any deviation in temperature and corrects the valve position.

PRESSURE CONTROL

A pressure control valve is necessary to spill-off surplus oil from the pump, to regulate any flow variation due to temperature fluctuations, and to accommodate any changes in demand from the machine being lubricated. The following are typical methods of control.

Spring-loaded relief valve — Provides coarse control and is sensitive to viscosity changes. Generally used on smaller, simple systems.

Copyright © 1983 CRC Press LLC



Direct-operated diaphragm valve — The diaphragm chamber is connected so that system pressure is transmitted to the diaphragm. The spring counter-balancing the diaphragm load is adjustable and determines the system pressure. Any change in demand will tend to vary the system pressure and the diaphragm, sensing this, will reposition the valve to adjust the spill-off rate. This valve will maintain the pressure within acceptable limits provided the viscosity remains reasonably stable.

Pneumatically controlled diaphragm valve — The diaphragm is air actuated via a control instrument. This valve is normally selected when very accurate control is necessary or if the system operating pressure is too great for the direct-acting valve diaphragm.

Header tank — While space requirements often preclude this simple form of control, the procedure is to place a tank at the required height. Filled directly with a line teed off the main pump supply, the tank is fitted with an overflow connection. This method ensures the continual change of tank contents to maintain the oil at system temperature. As an added advantage, if the system pumps fail the tank will discharge its contents via the fill connection to the equipment being lubricated. Pump check valves will prevent oil returning directly to the main reservoir.

Providing different pressures within the same system involves the use of pressure-reducing valves. These normally comprise a restricting orifice, or valve opening, which is controlled by imposing the outlet pressure on the valve control diaphragm.

EMERGENCY EQUIPMENT AND SYSTEM CONTROL

If a machine must continue to run after a failure in the lubrication system main pump, it is imperative to arrange fully automatic starting of a second, and maybe a third pump. This can be done by use of flow or pressure-operated switches, or both. Control panel lights

Copyright © 1983 CRC Press LLC

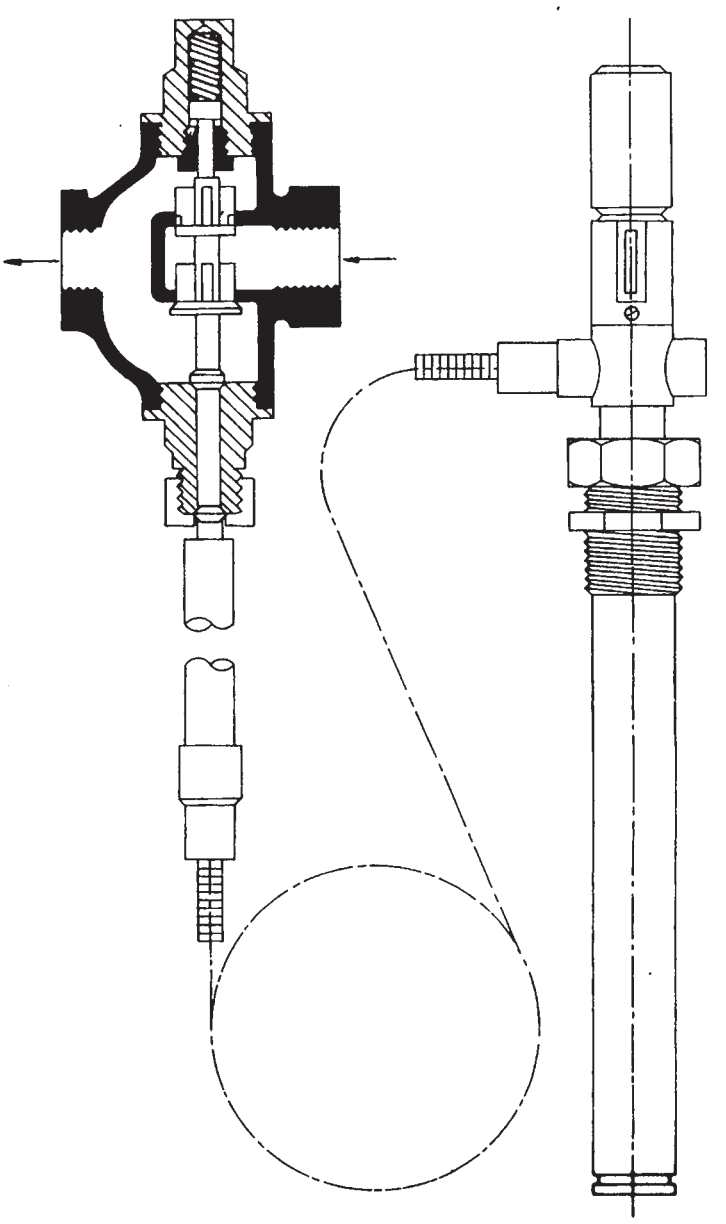


FIGURE 3. Thermostatic valve.

should indicate that normal running has been interrupted. A continued fall in pump output, due to failure of the emergency action, will operate switches which give an alarm signal and, if desired, cause the machine to stop.

Should it be impractical to stop the machine immediately upon failure of the lubrication system, a header or pressure tank may be incorporated downstream of the cooler to provide a diminishing supply of oil for up to 5 min (see Figure 5). The pressure tank is designed so that air trapped in the top at system pressure will force oil from the bottom when pump pressure is lost. To calculate total volume of the pressure tank, first decide the quantity of oil, Q, required for emergency purposes. Using Boyle's law, P1V1 = P2V2 where P1V1 = pressure (absolute) and volume of air, oil system operating; and P2V2 = pressure

Copyright © 1983 CRC Press LLC

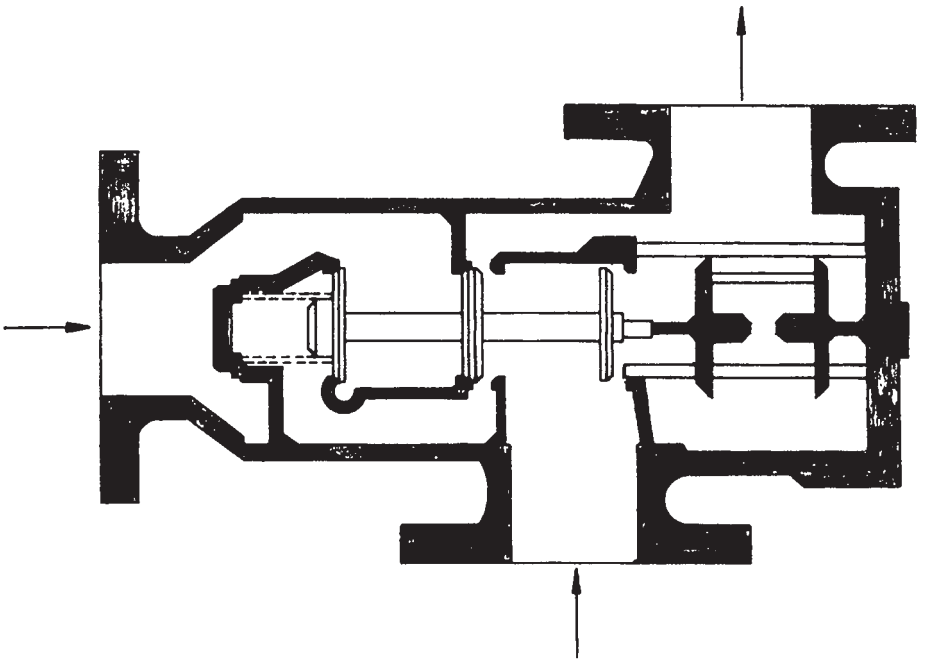


FIGURE 4. Three-way mixing valve.

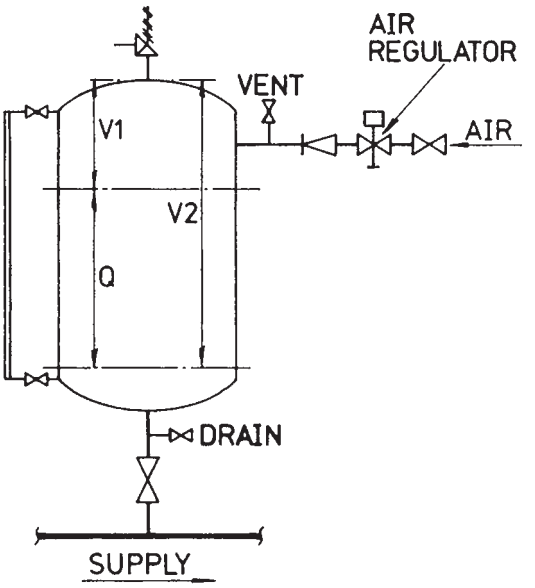


FIGURE 5. Pressure tank.

(absolute) and volume of air, oil system at rest; since V2 = V1 + Q; therefore V1 = P2(V1 + Q)/P1. Total volume of tank = V1 + Q + volume of bottom dished end. When the system is operating, the tank should be adjusted until the required quantity of oil is visible in the tank level glass, Q + volume of bottom dished end (normally two-thirds full).

To ensure that this balance between the air/oil volumes is not upset when the system is stopped, the tank should not be fully discharged. For this reason, the volume of bottom

Copyright © 1983 CRC Press LLC

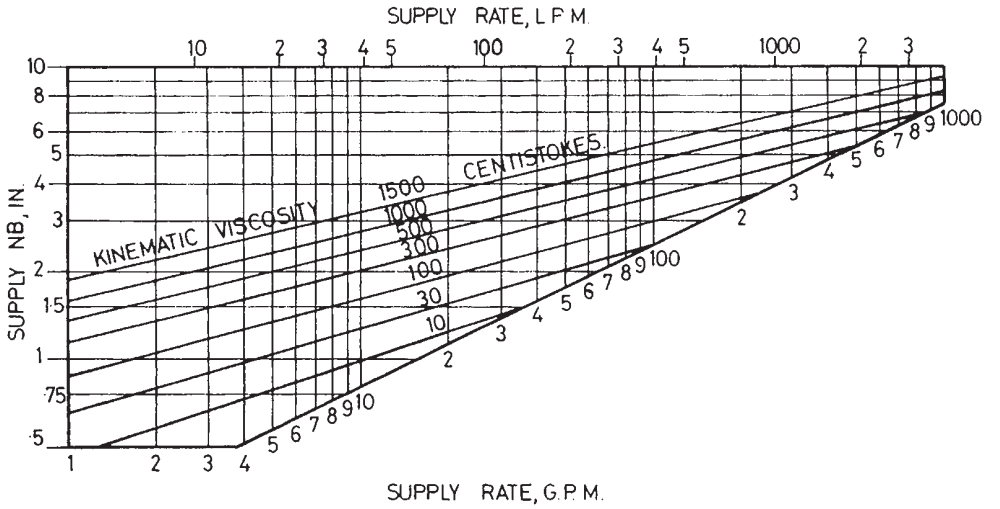


FIGURE 6. Supply line sizing.

dished end is included in the tank sizing calculations. As some air will be absorbed in the oil, it will be necessary from time to time to add air. A check valve should be fitted in the air supply line to prevent oil from entering the air main and an air regulator installed to avoid accidental overpressurizing.

SYSTEM PIPING

Sizes of interconnecting pipes should be considered in relation to oil viscosity, velocity, and resultant friction losses. Pipes should be large enough to prevent cavitation in pump suction lines, to avoid undue pressure drop in pump supply lines (minimizing pump drive power), and to avoid backup in drain lines.

Suction

Pipe runs should be short. Right angle bends and tee pieces should be kept to a minimum. Nominal bore of pipe to be one size larger than supply.

Supply

Friction loss due to viscosity frequently outweighs velocity considerations, particularly with heavier oils. Figure 6 is based on a friction loss of 0.1-m head per m of pipe and restricted to velocities under an acceptable 2 m/ sec. The viscosity at specified operating temperature should be used to determine pipe nominal bore.

To determine the friction loss in pipework, multiply the length by 0.1 m head. Friction loss caused by fittings and valves can be determined by converting them to equivalent pipe lengths in Table 2. These, together with pressure losses through the filter and cooler, will determine the system losses.

Drain

Drain pipes should be sized to run not more than half full so as to encourage escape of entrained air, provide space for any foam and give a margin of safety. Drain pipes should be vented. Flow rate, slope, and viscosity govern their size. A minimum slope of 1 in 40 is essential but use should be made of all available drop.

The pipe nominal bore may be determined from Figure 7. At startup, pipework and any

Copyright © 1983 CRC Press LLC

Table 2
EQUIVALENT LENGTHS OF FITTINGS

Fitting/valve	Equivalent lengths in pipe diameters
45° Elbow	15
90° Elbow	25
Tee	60
Gate valve	6
Globe valve	300

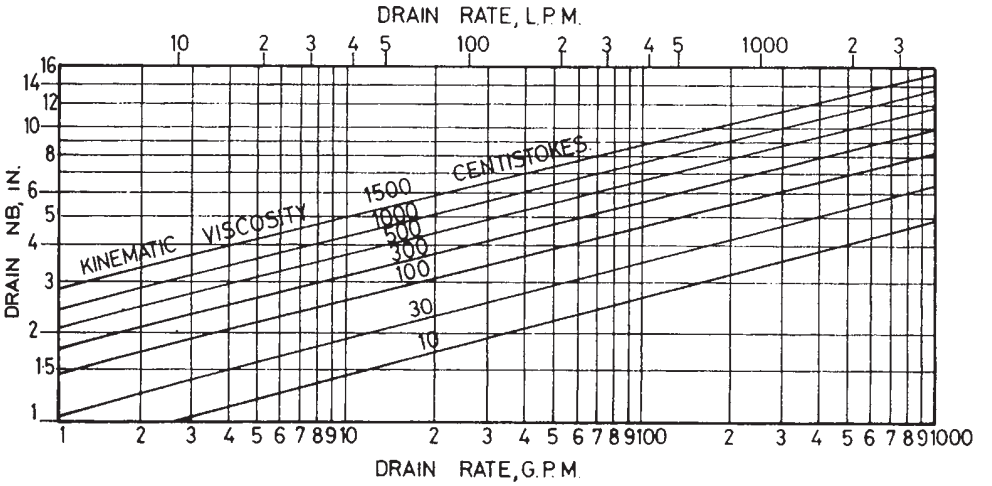


FIGURE 7. Drain line sizing.

oil retained in the machine sumps will be coid, and the oil viscosity at ambient temperature should be used to determine pipe nominal bore.

Cleanliness

Many troubles and faults experienced with lubrication systems arise from internal bores not being clean at final installation. Steel pipe must be internally shotblasted or pickled and phosphated before fabrication. All components and pipe fittings should be inspected for internal cleanliness. During fabrication, care must be taken to ensure that bores are kept clean. All welds should be mechanically cleaned, and completed pipe fabrications may also be chemically cleaned. During shop assembly or prior to dispatch of pipes to site, all bores should be internally oiled to prevent corrosion.

Following site installation, chemical cleaning may be carried out while bypassing bearings, gearboxes, etc. The system should then be flushed for 48 hr, again bypassing bearings, gearboxes, etc. The pipework should be hammered and oil temperature varied between ambient and 70°C at 4-hr intervals by adjustment to reservoir heating. For the first 24 hr the filter elements should be removed. After 48 hr or when filter elements remain clean, the system should be drained, reservoir cleaned, and machine piping connected.

Copyright © 1983 CRC Press LLC